

## HEAT EXCHANGING APPARATUS AND METHOD OF MANUFACTURE

### BACKGROUND OF THE INVENTION

#### Field of the Invention

The present invention concerns apparatus for effecting heat transfer, and a method of making such apparatus.

#### Discussion of the Known Art

Current trends toward miniaturization of electrical and electronic devices, have yielded products that need efficient heat dissipation in order to operate properly. This is due to the fact that such products typically consume a relatively large amount of electrical current with respect to their physical size. Cooling techniques such as, e.g., metal heat sinks and fans are used to maintain the operating temperatures of electronic components and devices at safe values, so that they will continue to operate over their expected lifetimes without failure caused by excessive heating. In particular, semiconductor and other solid state devices designed to operate at high power levels are

typically joined to finned, cast aluminum heat sinking structures. Adequate heat dissipation is especially important for electrical power supplies, radio frequency transmitters, modern desk-top and notebook computers, cellular telephones, and most all modern consumer electronics products.

It is generally known that structures used for transferring heat away from a heat source should have relatively high thermal conductivities (i.e., low thermal resistance), and have exposed surfaces of sufficient area to allow heat conducted from the source to radiate into a lower temperature environment. Further, the physical interface between a heat sink structure and its associated heat source should extend over as large an area as possible with minimal thermal resistance. Use of thermally conductive pastes such as a zinc-oxide silicone compound at the interface is a common practice. The compound fills air voids that are created when part of the heat sink structure is joined against a surface of a component to be cooled. In the absence of such a compound, the air voids act as thermal insulators and reduce the overall efficiency of the heat sink structure.

Heat sink configurations in the form of aluminum or copper radiating fins are also arranged on the circumference of heat pipes through which a working fluid (i.e., a liquid or

1 a gas) is conducted, to transfer heat from one location to  
2 another. The fins are typically joined to the pipes by  
3 friction, solder or epoxy. Discontinuous interfaces between  
4 the fins and the associated pipe typically present significant  
5 thermal resistance, and the efficiency of heat transfer is  
6 compromised accordingly. Also, the effective contact area  
7 between a heat pipe and its surrounding fins is generally  
8 limited due to the process by which the fins, usually made of  
9 sheet metal, are formed. Moreover, the fins are often  
10 attached manually one at a time, making the assembly procedure  
11 labor intensive and costly.

12 It is also known that certain electronic components  
13 or devices may be encapsulated with a conductive plastics  
14 compound to form heat radiating surfaces about the devices.

15 The geometry of the radiating surfaces is, however, limited by  
16 the flow characteristics of the plastics compound, its brittle  
17 nature when loaded with a material to increase its thermal  
18 conductivity, and a generally lower radiating efficiency in  
19 comparison to that obtained with most metals.

20 U.S. Patent 5,040,589 (Aug. 20, 1991), discloses a  
21 method and apparatus for injection molding of metal alloys,  
22 wherein a selected alloy is heated to a thixotropic or semi-  
23 solid state, and then injected as a slurry into a mold to form

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As far as is known, however, injection molding of metals has not been used to produce heat exchanging structures directly on thermally conductive core objects or heat sources.

## SUMMARY OF THE INVENTION

According to the invention, heat exchange surfaces are formed on a core object by placing at least a part of a thermally conductive core object within a mold cavity formed to define one or more heat exchange surfaces, injecting a heated metal slurry into the mold under a predetermined pressure, and cooling the heated metal slurry thus forming a

substantially continuous void free interface between the core object and the metal slurry when hardened for effective heat transfer across the interface.

5           For a better understanding of the invention, reference is made to the following description taken in conjunction with the accompanying drawing and the appended claims.

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## BRIEF DESCRIPTION OF THE DRAWING

In the drawing:

FIG. 1 is a schematic representation of a heat exchange assembly having a core pipe and associated heat exchanging fins, according to the invention;

FIG. 2 is a perspective view of a heat exchange assembly similar to the assembly of FIG. 1;

FIG. 3 illustrates a molding process for producing a heat exchange assembly according to the invention;

FIG. 4 is a scanning electron microscope (SEM) image of an interface between a core pipe and associated heat exchanging fins, according to the invention;

FIG. 5 is a graph identifying relative amounts of metallic elements at both sides of the interface in FIG. 4;

FIG. 6 illustrates a cooling system for an electronics equipment enclosure, according to the invention;

FIG. 7 shows a part of the cooling system of FIG. 6;

FIG. 8 is an assembly view of a heat sink arrangement for an electronic component, according to the invention;

FIG. 9 is an assembly view of a baseboard heating system, according to the invention;

FIG. 10 illustrates an automotive radiator assembly, according to the invention;

FIG. 11 illustrates an environmental cooling system, according to the invention;

FIG. 12 is a perspective view of a half mold or die plate used in the present method; and

FIG. 13 is a detail view of one end of the half mold shown in FIG. 12.

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## DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 represents a model of a heat exchange assembly 10, according to the invention. The assembly 10 includes a core pipe 12 made of copper or equivalent material having relatively high thermal conductivity, and one or more heat exchanging fins 14 which are closely joined as a unit about the circumference of the core pipe 12. The fins 14 are made of, for example, a magnesium alloy (e.g., type AZ91D) which is capable of being heated to a thixotropic state, and then injected as a slurry into a mold cavity under pressure whereby the fins 14 are formed on the core pipe 12, as explained further below. The material forming the fins 14 also has a relatively high thermal conductivity, for example, about 42 BTU/ft·hr·deg F for the mentioned type AZ91D magnesium alloy. The fins 14 are formed with a common cylindrical base 16 whose inner circumference establishes a substantially continuous, void-free interface 18 with the outer circumference of the core pipe 12 once the molded, heated slurry is allowed to cool and harden. The interface 18 between the inner circumference of the fin base 16 and the outer circumference of the core pipe 12 thus ensures an efficient heat transfer across the interface 18 in either direction.



FIG. 2 is a perspective view of a heat exchange assembly 20 which was constructed according to the model in FIG. 1. The assembly 20 has a copper core pipe 22 and a total of seven circular heat exchanging fins 24. The pipe 22 has an outer diameter of about 0.375 inches, an inner diameter of 0.300 inches, and an overall length of 6.0 inches. Each of the fins 24 has a diameter of about 2.0 inches, and extends radially from a common cylindrical base 26 whose outer diameter is about 0.500 inches. The fins 24 are each about 0.040 inches thick, and are spaced apart from one another in the axial direction by about 0.375 inches. The material used to form the heat exchanging fins 24 was a magnesium alloy type AZ91D. The alloy was initially heated to about 900 degrees F, and then injected as a thixotropic slurry into a mold cavity in which the copper core pipe 22 was previously placed and supported along an axis of the cavity. The injection pressure was approximately two tons per projected square inch.

FIG. 3 depicts a process by which the heat exchange assembly 20 of FIG. 2 and other heat exchange devices can be manufactured, according to the invention. A series of die plates or half molds 32 are arranged in tandem for linear movement about the perimeter of an injection molding machine 34. Another series of die plates or half molds 36 are arranged in tandem for linear movement about the periphery of

another injection molding machine 38, which may be substantially identical to the machine 34. The die plates 32 and 36 may also be substantially identical to one another. See FIGS. 12 and 13. The molding machines 34, 38 are positioned so that corresponding ones of the die plates 32, 38 will face one another while being displaced by the machines 34, 38 along a common direction of travel shown by arrows 40 in FIG. 3.

As seen in FIG. 12, each die plate 32, 36 forms a half-mold cavity 37 defining corresponding upper or lower halves of the heat exchanging fins 24 and common cylindrical base 26 of the assembly 20 in FIG. 2. A number of pairs of the die plates which face one another over a portion of the travel path 40, are urged by the associated machines 34, 38 into a closed position thus forming full mold cavities within them. Guide pins 41 on either one of the confronting die plates 32, 38 enter corresponding openings 43 formed in the other die plate, so that the confronting plates 32, 38 are properly aligned as they close against one another. Inlets 39 that open at the back of each die plate 32, 36, communicate through a passage in the die plate with the half mold cavity 37. As shown in FIG. 3, the inlets 39 of the die plates are positioned to align with corresponding chambers 47 in the

machines 34, 38. A heated thixotropic metal slurry is then discharged from the machine chambers 47 into the die plate inlets 39 at a predetermined pressure and time interval.

Further, as shown in FIG. 13, axial ends of each of the die plates 32, 36 have a semi-circular cutout 44 which is formed with raised semi-circular ribs 46 each having, e.g., a triangular cross section. Thus, when pairs of the die plates 32, 36 close with one another, a core pipe 42 (FIG. 3) can extend axially through the cutouts 44 in all the closed pairs of the die plates 32, 36, with insubstantial leakage when heated material is injected into the mold cavities 37 within the closed plates. That is, the raised ribs 45 create an interference fit between the outer diameter of the core pipe 42 and the inner periphery of the cutouts 44 in each of the die plates 32, 36. The ribs 46 deform the softer pipe 42 (or other core part) radially by, e.g., a few thousandths of an inch, similar to compression fittings known in the plumbing, automotive and utility fields. Depending on the wall strength of the pipe 42, it may be necessary to insert a solid rod or mandrel 48 inside the pipe, as shown in FIG. 3, in order to prevent deformation or collapse of the pipe wall in response to the outside pressure of the injected slurry.

FIG. 4 is a scanning electron microscope (SEM) image

showing a contact interface 50 between a magnesium alloy base 52 that was injection molded over a surface of a copper pipe 54. Specifically, a type AZ91D magnesium alloy was injected at about 900 degrees F into a mold cavity containing the copper pipe 54, within about 1/10th of a second at a pressure of about two tons per projected square inch. The image of FIG. 4 represents a 2,000 magnification setting for the SEM, and a distance of 10  $\mu\text{m}$  is shown by a scale line 56. As seen in FIG. 4, interface 50 is substantially continuous and void-free.

FIG. 5 is a graphic representation showing relative amounts of metallic elements at both sides of the interface 50 in FIG. 4. Units of distance (arb) along the x-axis in FIG. 5 are such that about 2,200 arb units equals 50  $\mu\text{m}$ . A region about the interface 50 wherein both copper and magnesium elements are detectable, extends over only about 140 arb units or 3  $\mu\text{m}$ . That is, the interface 50 is quite sharp. Relatively small counts of Mg and Cu appear at opposite sides of the interface 50 because background was not subtracted in the graph of FIG. 5.

FIG. 6 shows a cooling system 70 for an electronics equipment enclosure 72, and FIG. 7 shows a part of the cooling system 70 in FIG. 6. One or more heat conductive pipes 74

have a number of heat radiating fins 76 molded over end portions of each of the pipes 74, according to the present invention. Central portions of the pipes 74 intermediate the end portions form a 180 degree bend and are supported in thermal conducting relation within or in contact with a source of heat, for example, a chassis, a power supply cabinet, or other heat-generating electrical equipment 78. A vapor barrier or environmental gasket 80 made of, e.g., a soft elastomer or rubber material creates a water-tight seal between the heat pipes 74 and the equipment 78.

An air blower 82 disposed, e.g., at the bottom of the equipment enclosure 72 directs an outside air flow 84 past the sets of radiating fins 76 on each of the pipes 74. Accordingly, heat conducted by the intermediate portions of the pipes 74 away from the heat source 78, is dissipated via the radiating fins 76 and the air flow 84 to the outside environment.

FIG. 8 is an exploded view of a heat sink device 90 for an electronic component 92, e.g., a processor chip. A relatively thin metal subframe 94 is fastened over one or more surfaces of the component 92, and placed with the component inside an injection mold cavity which defines a number of vertical heat dissipating elements in the form of, e.g.,

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cylindrical rods 95. A thixotropic metal slurry is injected into the cavity and adheres to the thin metal subframe 94 while filling voids in the cavity corresponding to the rods 95. Perforations 96 in the subframe 94 are also filled with the  
5 injected slurry to form mechanical "locks" between the slurry when cooled and hardened, and the subframe. The thin metal subframe 94 aids in protecting the component 92 from the elevated temperature of the slurry while in the mold cavity.

When the component with the subframe 94 and integral rods 95 are removed from the mold cavity, the completed assembly may be mounted on, e.g., a printed wiring board via fasteners (not shown) that pass through mounting holes 99 in side flanges 98 of the subframe 94, and the wiring board. Contact pins or leads of the component 92 may then be soldered  
15 or otherwise connected to corresponding conductors associated with the wiring board.

20 FIG. 9 is an assembly view of a baseboard heating system 100. The system 100 comprises a core heat conducting pipe 102 through which a heated working fluid (e.g., hot water) is circulated by an outside pump (not shown). A number of heat radiating fins 104 are formed with a common cylindrical base 106 on the outer circumference of the fluid pipe 102, by way of an injection molding process such as that

described in connection with FIG. 3. Various length sections of the fluid pipe 102 with the molded radiating fins 104 may be produced initially, and then connected to one another through straight or angled pipe couplings to fit a particular application. Once in place, a slotted protective cover 108 is fastened over the pipe 102 and the associated fins 104.

FIG. 10 shows an automotive radiator assembly 120. A number of heat conductive (e.g., copper) metal core pipes are arranged parallel and co-planar with one another, after a series of heat radiating fins 124 are molded with a common cylindrical base 126 over each of the pipes 122 per the present method. Opposite open ends of the pipes 122 are joined in fluid communication with corresponding header or end pipes 128, 130. When heated engine coolant is pumped through one of the end pipes 128, 130, the coolant is directed through each of the core pipes 122 and cooled by outside air which has been directed to flow over the radiating fins 124 on the pipes 122. The coolant is then returned through the opposite end pipe to be pumped and circulated through an associated engine.

FIG. 11 illustrates an environmental cooling system 150. One or more sections of a heat conducting, metal core pipe 152 have a series of heat exchanging fins 154 with a common cylindrical base 156 molded over the outer

circumference of the pipe 152, according to the present method. A cooled working fluid such as, for example, an evaporated refrigerant, water or air is directed under pressure through an inlet 158 of the pipe 152. Warm air to be cooled is directed by outside means (e.g., a blower or fan) between the fins 154 so that the fins absorb heat and conduct it through the fin base 156 and the pipe 152 into the working fluid. The heated working fluid exits from an outlet 160 of the core pipe 152, and cooled air 162 is available to be channeled where desired by suitable means.

The various heat exchanging apparatus disclosed herein are highly efficient because of the formation of a substantially continuous, void-free thermal interface between a thermally conductive core pipe or tube, and a number of heat exchanging fins which are injection molded under pressure over the pipe rather than being formed and attached individually. The present injection molding process may also yield fins having thinner cross-sections and less weight than conventional fins. Magnesium and aluminum alloys are highly thermally conductive materials having high strength-to-weight ratios, and are both well suited for injection molding into the form of heat radiating or cooling fins according to the present process.



Importantly, the present process yields an increased contact area between a number of heat exchanging fins and their associated core pipe or component when compared to prior configurations using individual fins. The process can be used to form heat sink configurations for various electronic devices and products that must operate with adequate cooling, including large scale installations such as wireless telephone base stations where heat generated by a number of active radio transceivers within a confined space must be dissipated in an effective and efficient manner.

While the forgoing description represents preferred embodiments of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from the spirit and scope of the invention pointed out by the following claims.